# Scale Resolving Simulations of Contra Rotating Open Rotor Noise Prediction

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# Introduction

The growing concerns about the environment and the rising costs of energy have brought open-rotor propulsion systems into the spotlight as a potential solution for future commercial transport aircraft

- ✓ Offering substantial amount of fuel efficiency
- ✓ Significant reduction of $CO_2$ emission

The present work aims to demonstrate the readiness of analysis tools in exploring the aerodynamic and aero-acoustic characteristics of Contra-Rotating Open Rotor (CROR) propulsion systems, leveraging well-documented experimental data

# Experimental Cases

CROR installed in 9 by 15 ft Low Speed Acoustic Wind Tunnel(*)

- ✓ Blade pitch angles were 40.1 & 40.8 degrees
- ✓ Mach 0.2, rotating at a constant 6303 RPM
- ✓ All data recorded sound Pressure Spectral Densities
- ✓ Total 18 microphone stations, radially 1.52 meters away from CROR

CROR installed in 8 by 6 ft SWT with Kulite plate above (*)

- ✓ Blade pitch angles were 64.4 & 61.8 degrees
- ✓ Mach 0.2, rotating at a constant 6848 RPM
- ✓ All data recorded sound Sound Pressure Level
- ✓ Total 17 Kulite attached to the "***acoustic plate***" at five different vertical stations

(*)Stephens, D. B., "Data Summary Report for The Open Rotor Propulsion Rig Equipped with F31/A31 Rotor Blades," NASA/TM-2014-216676, 2014.

# Launch Ascent and Vehicle Aerodynamics (LAVA)

### Structured Curvilinear
- Design Optimization
- Mesh Redistribution
- Sliding and Immersed BC
- RANS & HRLES
- WMLES

### Structured Cartesian
- Adaptive Mesh Refinement
- Immersed Boundaries
- FSI & 6DOF
- Multi-Species & Multi-Phase
- WMLES

### Unstructured Polyhedral
- Voronoi Meshing
- Conjugate Heat Transfer
- Multi-Species
- RANS
- WMLES

### Pre-Processing Tools

### Far Field Acoustic Solver

## LAVA

C++ / Fortran / Python

MPI+OpenMP / MPI+CUDA

GitLab

### Space-Marching Propagation

### Post-Processing Tools

### Actuator Disk Models

### Combustion
Radiative Heating
…

***Active Efforts:***
- Low dissipation and higher order
- Wall modeled large eddy simulation
- Voronoi grid generation
- Design optimization
- Porting to GPUs and cloud compute
- Roadmap to release

Existing | Developing | Future | Framework

# Methodology

The Launch Ascent and Vehicle Aerodynamics (LAVA) computational framework serves as the foundation for all computational studies presented in this work

- ✓ Utilizing a *third-order modified Roe scheme* for the nominal takeoff condition

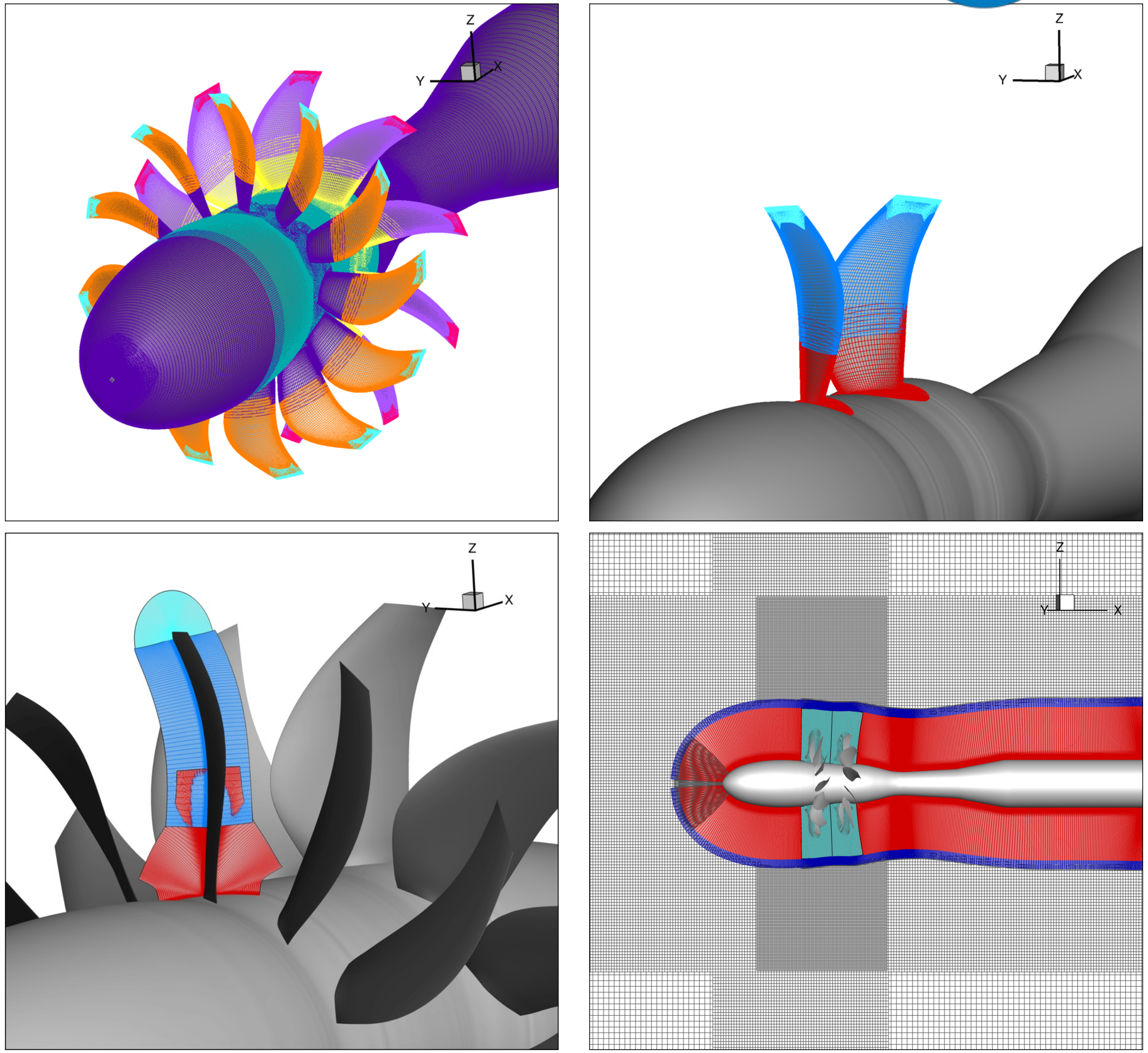
- ✓ Employing a *modified third-order high speed upwind scheme* featuring a local shock sensor-based WENO limiter and the Ducros sensor specifically tailored for *the cruise condition*

# Structured Overset Grid System

- ✓ Near-body meshes were generated utilizing Chimera Grid Tools (CGT) with a script that built a fully automated mesh for various flight conditions

- ✓ The octree-based overlapping off-body Cartesian grid was generated using the built-in module in the LAVA framework

- ✓ Hole cutting and connectivity were performed using the modules within the LAVA framework for the overset grid system



# Sensitivity Studies: Sole Focus on Nominal Takeoff - I

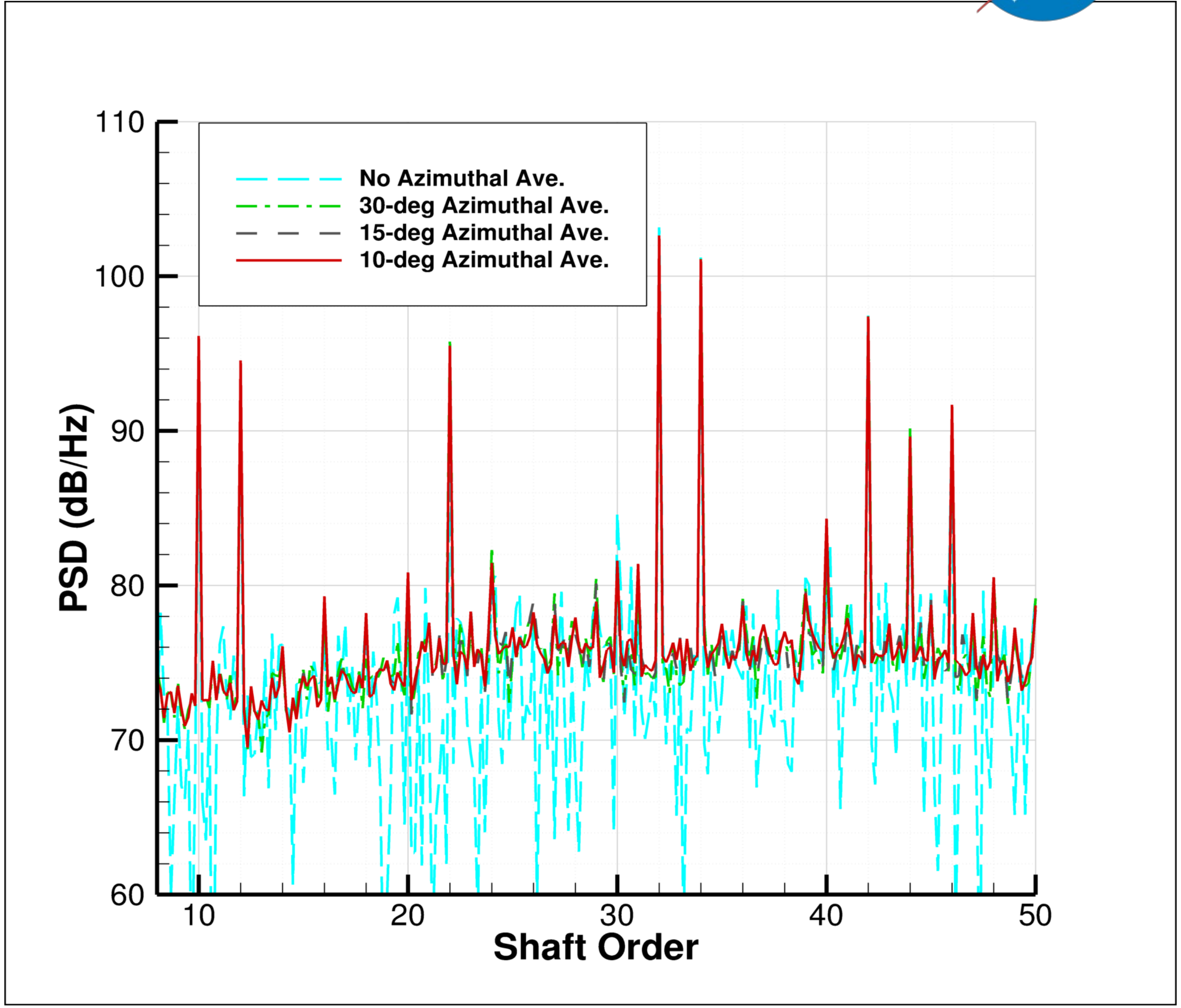
- ✓ The sensitivity study on 'acoustic propagation' included the computation of the Pressure Spectral Density at Microphone Location 8

- ✓ Key Insights :

  - The refinement of the acoustic surface was not as crucial as extending the acoustic surface further into the wake region to capture more acoustic features in this frequency range

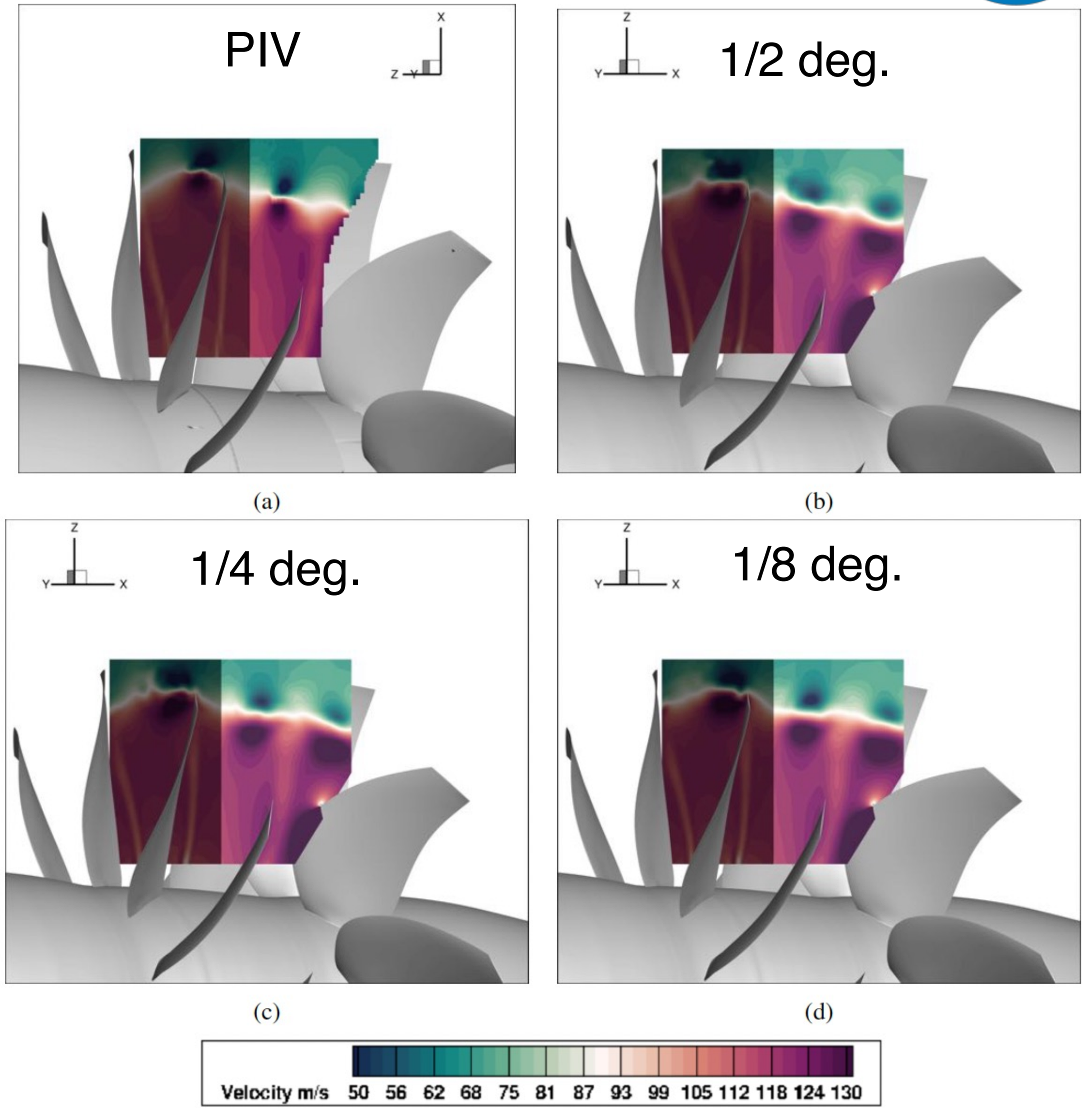
  - The disparities were below 1.5 dB when comparing four and five complete rotor revolutions to six complete rotor revolutions

  - Azimuthal averaging played a crucial role in minimizing variations in broadband noise levels, aligning them more closely with experimentally reported values



# Sensitivity Studies: Sole Focus on Nominal Takeoff – II

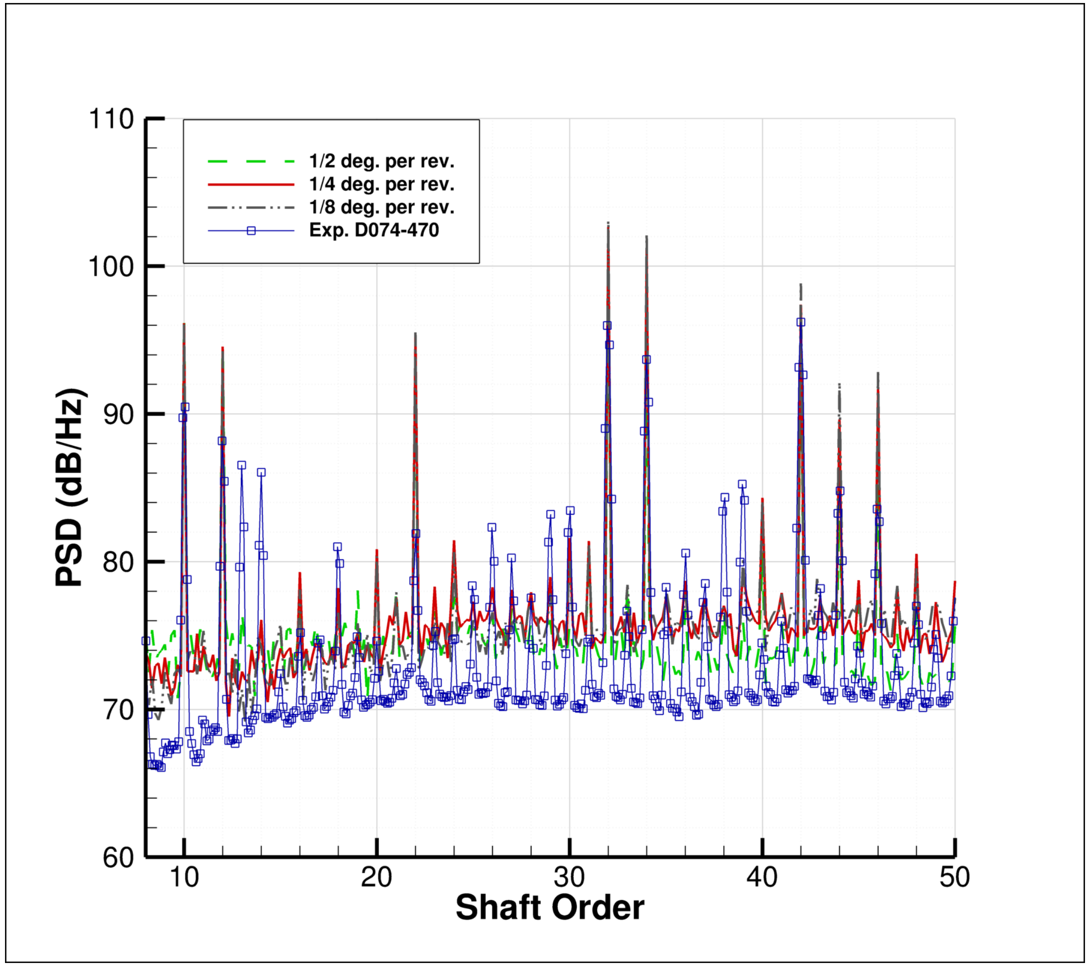
- ✓ Conducted a time-step sensitivity study on CROR's aerodynamic and aero-acoustic characteristics with physical time steps of 1/2, 1/4, and 1/8 degrees rotation-per-step
- ✓ Figures compare the ensembled averaging versus the instantaneous velocity magnitude contours
- ✓ The time-averaged computed thrust values showed less than 1% variation among the simulations and they were at most 5% larger than the measured thrust in the experiment

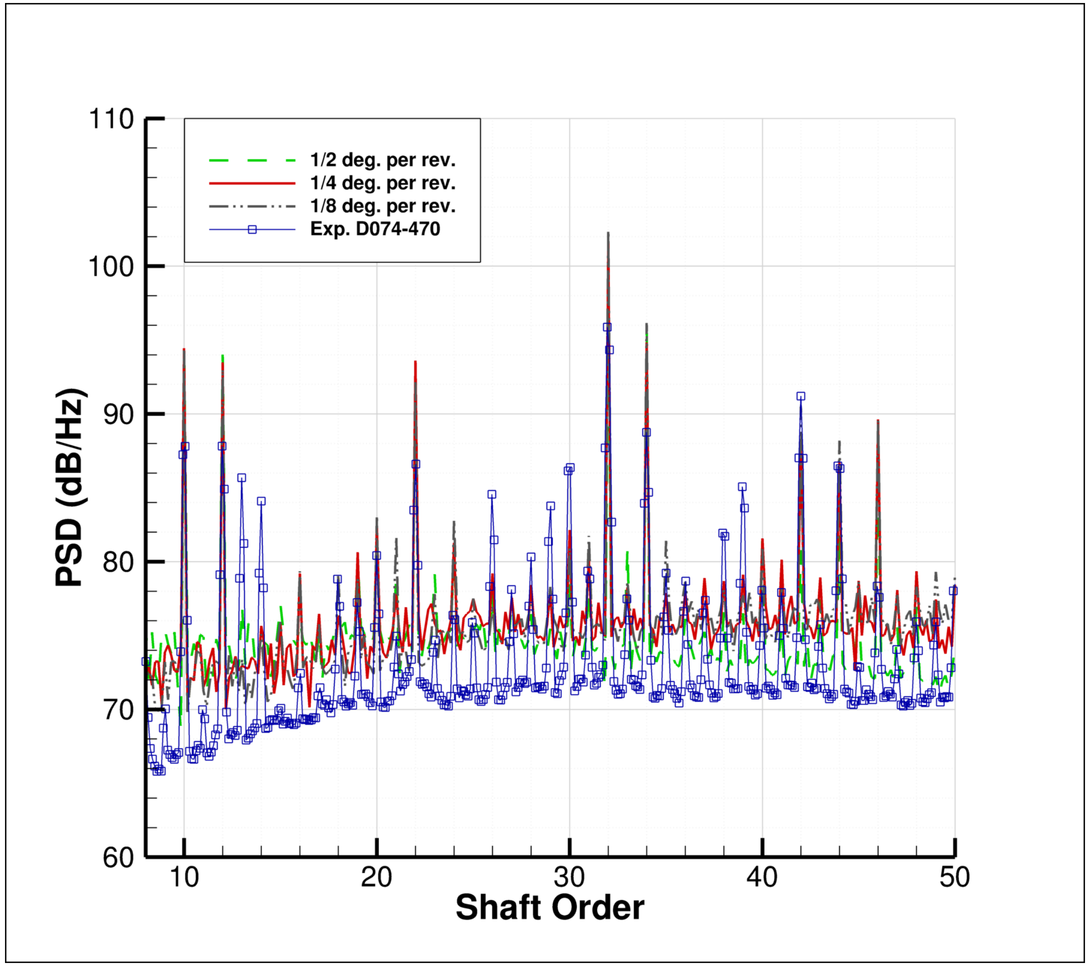


(a) (b) (c) (d)

# Sensitivity Studies: Sole Focus on Nominal Takeoff – III

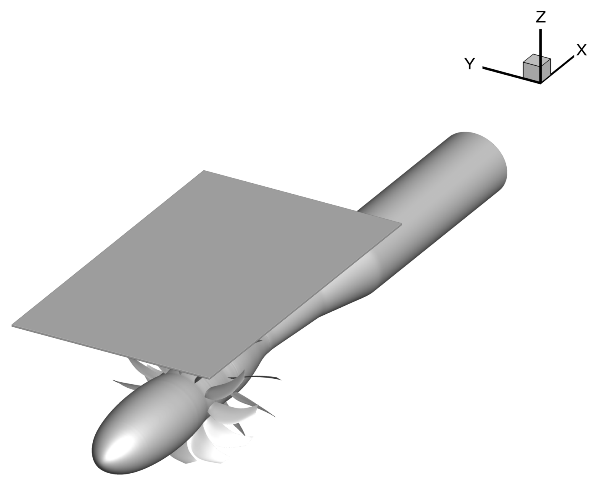
Microphones 8 and 9 were located 1.52 m radially away from the center of the aft and forward blade rows



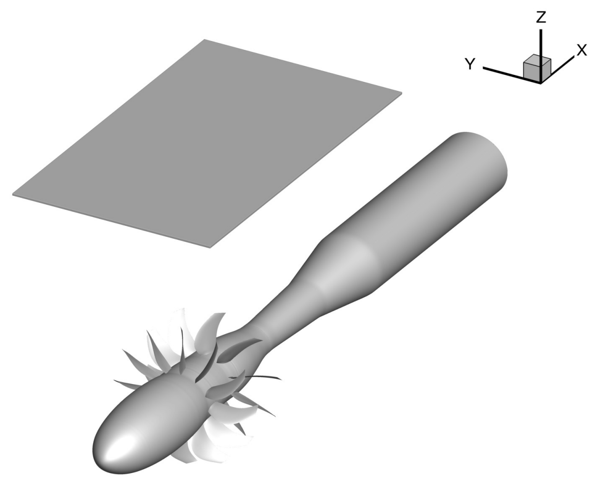



# The Cruise Condition - I

- ✓ The Influence of the acoustic plate on the computed flow field
- ✓ In pursuit of this understanding, adjustments were made to the overset grid system by incorporating the acoustic plate component at two vertical positions—0.51 and 1.16 meters away from the rotating axis
- ✓ Changes were exclusively made to the off-body Cartesian mesh system, ensuring a fine enough mesh to envelop both the forward and aft rotor rows, as well as the acoustic plate; resulting approximately 290 million grid points




0.51 meters

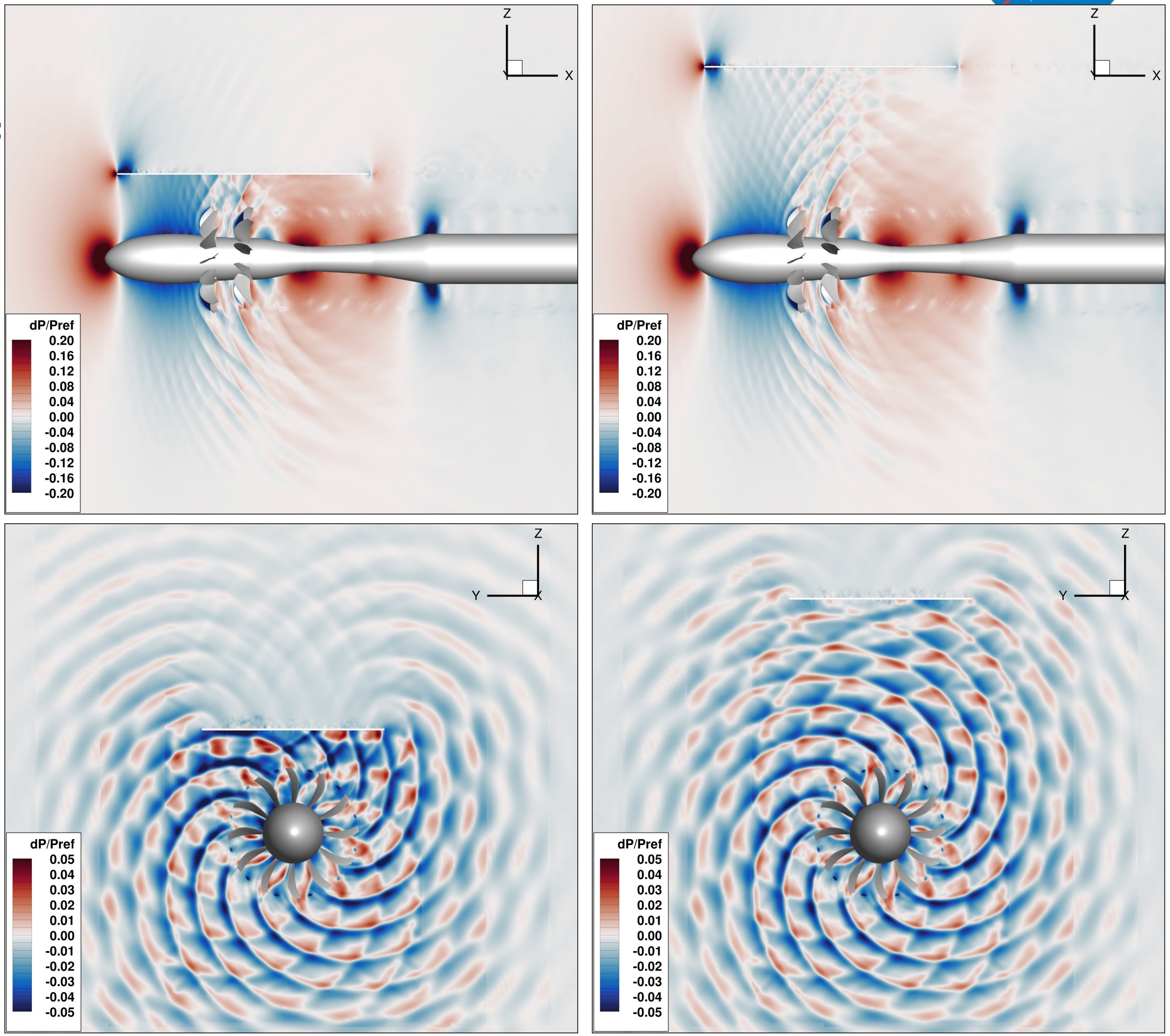



1.16 meters

# The Cruise Condition - II

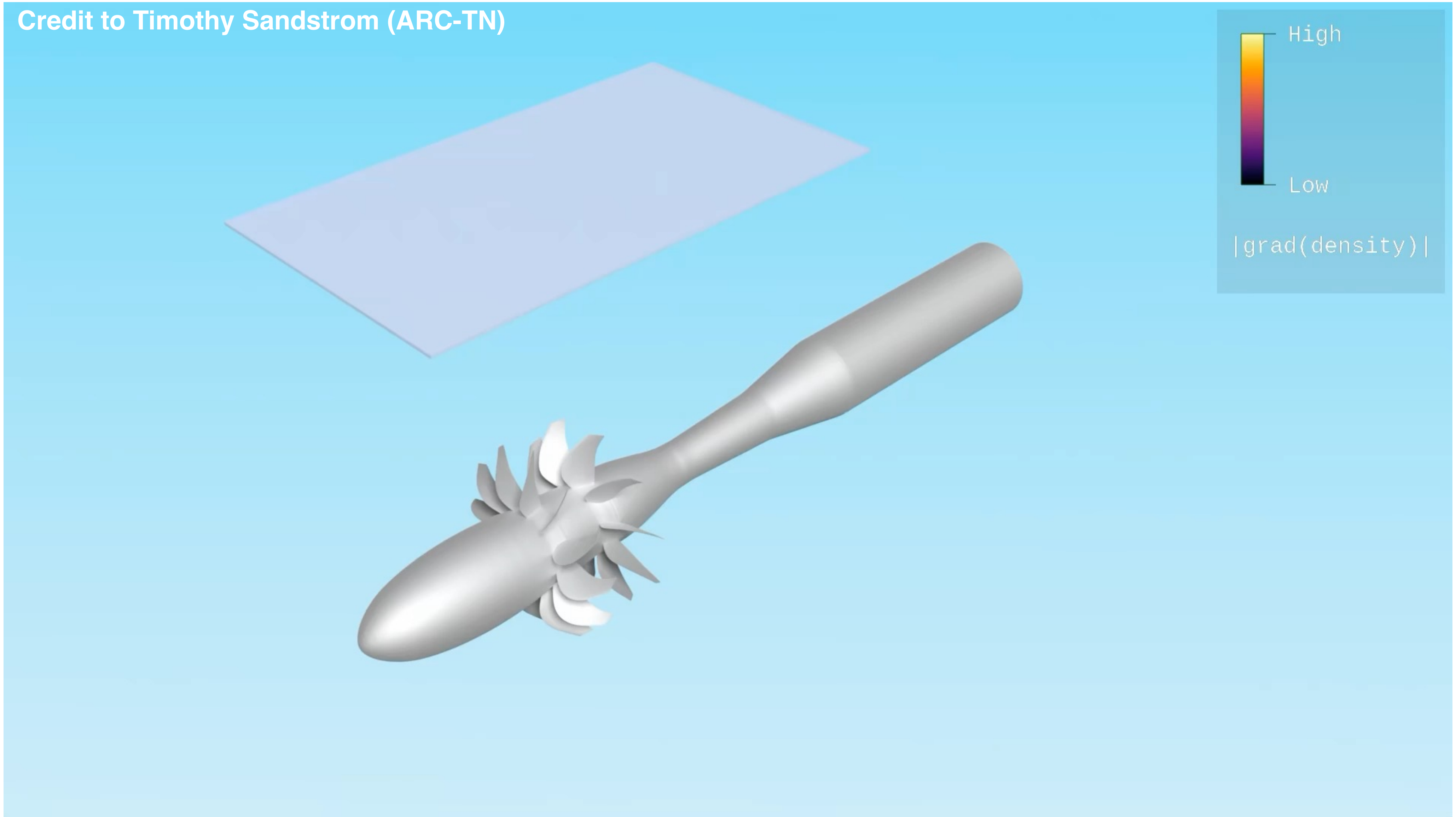
- ✓ When the acoustic plate was present, waves generated by the movements of both forward and aft blades reflected off the acoustic plate

- ✓ Evidence of a strong interaction between the waves generated by both the forward and aft rotors was observed



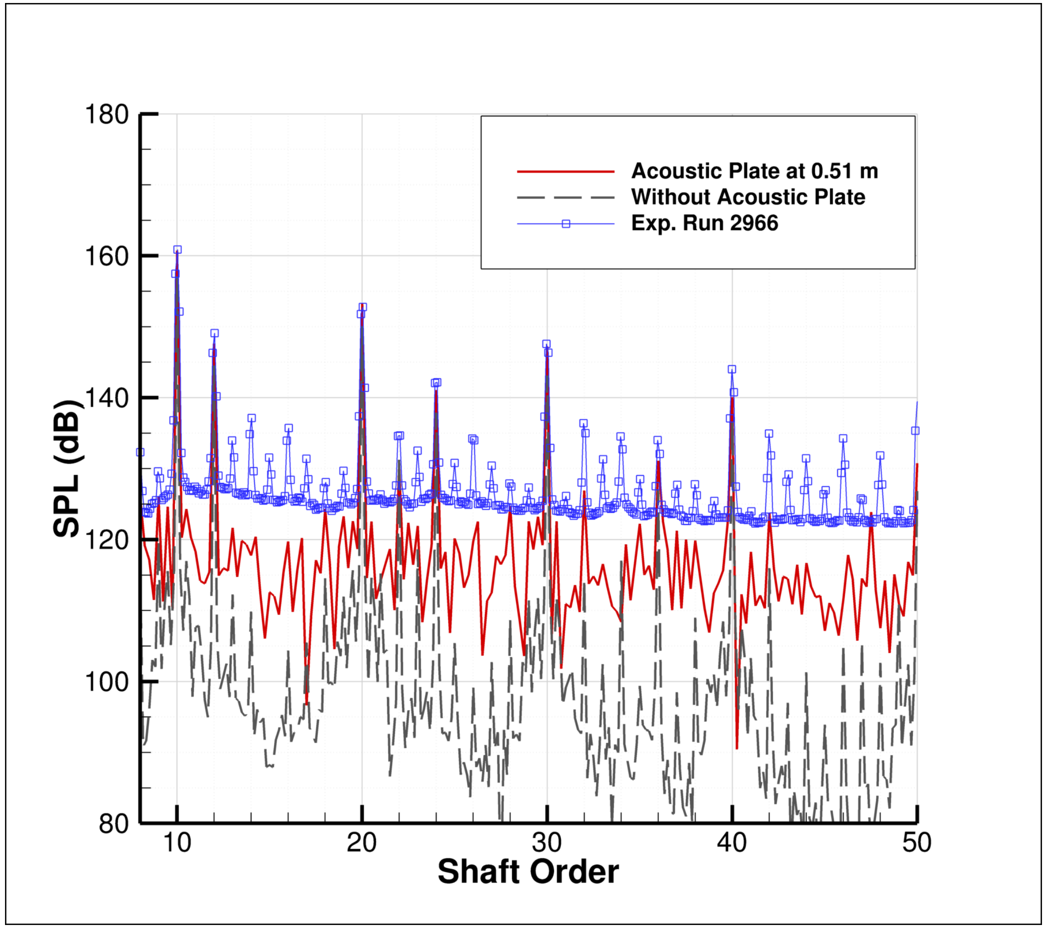
# The Cruise Condition Flow Animation

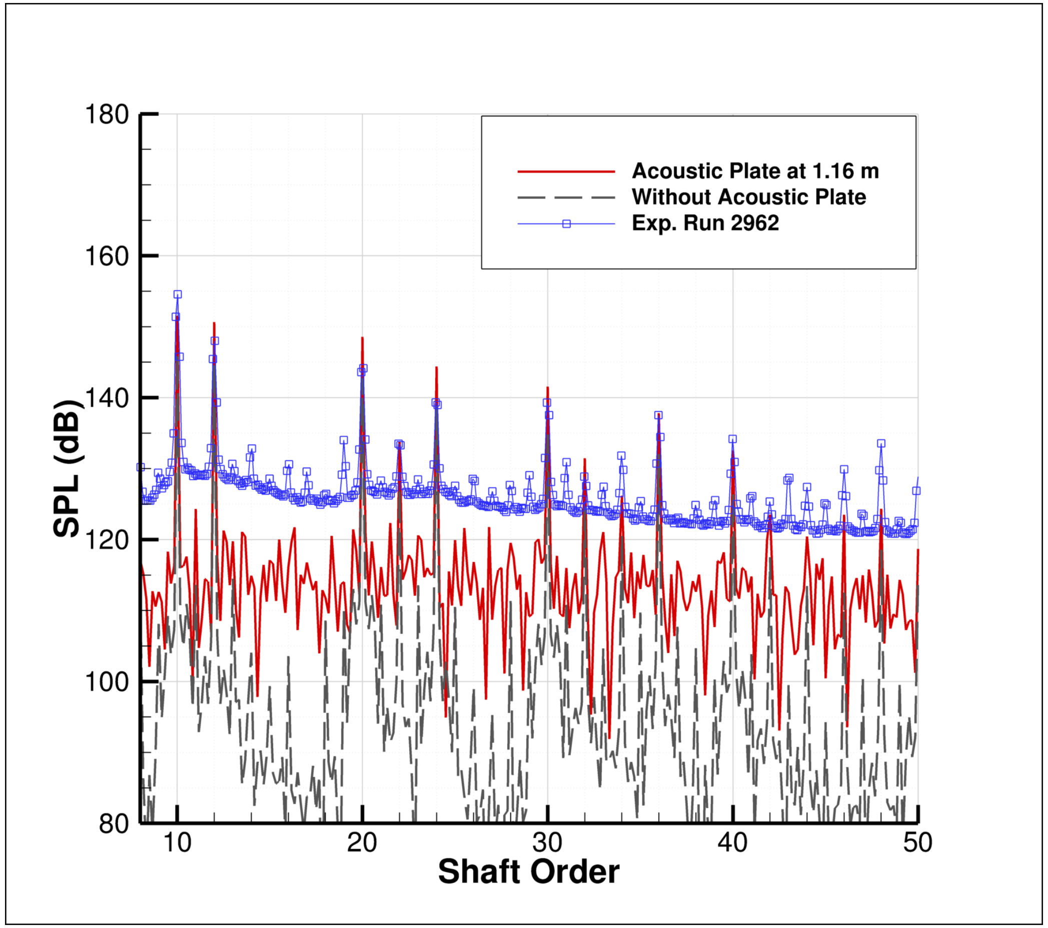
Credit to Timothy Sandstrom (ARC-TN)



# The Cruise Condition - III

✓ There is unmistakable evidence of "pressure doubling" when the acoustic plate is positioned at 1.16 meters. In this scenario, the difference in major tones is approximately 6 dB, excluding the Shaft Order of 46.



# Summary

The Launch Ascent and Vehicle Aerodynamics (LAVA) solver framework, using structured overlapping grids has been successfully applied to the prediction of tonal noise generated from a model scale contra-rotating open rotor propulsion system

- ✓ The computed flow field, integrated aerodynamic forces, and acoustic predictions derived from the LAVA solver demonstrated outstanding agreement under both nominal takeoff and cruise test conditions

- ✓ The findings presented in this publication inspire considerable confidence in the efficacy of LAVA best practices for predicting both tonal and broadband noise. Furthermore, these practices prove robust in evaluating interactions among the propulsor, wing, fuselage, and/or cabin

# Acknowledgement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# BackUp